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Effect of humate and controlled released NPK fertilizers (NPK-CRF) on rice yield and soil fertility of intensive alluvial soils

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Abstract

The study aims to assess the effect of mixed fertilizers, including controlled slow-release NPK (NPK-CRF) and urea, potassium humate fertilizers, on soil fertility and rice yield. The on-Farm Trials experiment was carried out on alluvial soil, with 2 models corresponding to 2 farming techniques: (i) Traditional fertilization, applying conventional fertilizers with the formula 92.2 N–82.8 P_2O_5–22.8 K_2O kg/ha; (ii) New generation fertilizers (NPK-CRF, urea humate, and potassium humate) with the formula 50.1 N–39.9 P_2O_5–30.0 K_2O. Each pattern was repeated three times, corresponding to 3 farmers. Each household's area is 1,000m^2, cultivating continuously through three seasons of Winter-Spring (WS), Summer-Autumn (SA), and Autumn-Winter (AW) in Chau Thanh A district, Hau Giang province. The results showed that the new generation fertilizer application significantly improved rice yield and yield composition of the Winter-Spring cropping season (6.92 tons/ha), Summer-Autumn (5.94 tons/ha), and Autumn-Winter (6.15 tons/ha), which are different from farmers' fields. Furthermore, the combined application of NPK-CRF, urea-humate, and K-humate fertilizers for rice in SA and AW crops significantly reduced the total acid content, Al^{3+} exchange in the soil and improved soil fertility of pH, N and available P, organic matter (%C). However, there was no difference in soil's physical properties over the three farming seasons. Finally, adding humic acid to controlled-release fertilizer can improve soil fertility and increase yield and yield components, nitrogen uptake, enhance nitrogen usage efficiency, all of which have positive yield and soil consequences.

Keywords

Controlled-release NPK, K-humate, NPK-CRF, urea-humate

Introduction

Three-crop rice cultivation has increased productivity and rice output. However, intensive farming and long-term use of chemical fertilizers lead to soil degradation and rice yield (1). Then causes high investment costs and low profitability. According to one report, inappropriate fertilizing and using a lot of chemical fertilizers is one of the causes leading to low fertilizer use efficiency of crops because fertilizers are lost in many ways, such as NH_3 leaching, overflow and direct sunlight, or denitrify (2). Slow-release or controlled-release fertilizers are fertilizers produced by new technology. The fertilizer advantage is that it integrates multiple elements, which is slower to dissolve than conventional chemical fertilizers; nutrients in manure provide more extended support to plants (3). Using slow-release or slow-release fertilizers with control in rice cultivation is considered one of the optimal solutions to reduce losses, increase fertilizer use efficiency for plants and save 20-30% of fertilizer. Fertilizers are compared to conventional fertilizers (4). Besides, the study also recorded an increase in rice yield, improved root structure, more extensive leaf area index and higher photosynthetic capacity when used (5).

Slow-dissolving fertilizer. On rice cultivation land, the restoration or maintenance of soil fertility mainly depends on the organic matter content of the soil (6). Research shows that humate salts such as K-humate and urea-humate can be used as alternative organic sources to improve physico-chemical and biological properties (7). Soil helps plants withstand adverse environmental conditions, helps plants grow well, and increases crop productivity. Research also shows that applying K-humate or urea-humate fertilizers helps reduce the number of chemical fertilizers and helps plants grow smoothly, increases nutrient absorption and improves crop yields (8). Using a combination of slow-release fertilizers helps achieve long-term sustainable outcomes when intensive farming, maintaining proper nutrient rotation in the soil-plant system. However, at present, most farmers in rice-intensive areas still fertilize according to custom, unbalanced fertilization, which increases production costs, reduces profits and causes degradation of the soil environment. Therefore, the experiment was conducted to evaluate the effectiveness of the combined application of controlled slow-release NPK fertilizer, K-humate and urea-humate in improving the fertility and yield of intensive rice on alluvial soils without accretion in the Mekong Delta, Vietnam.

Materials and Methods

Study site and materials:

The experiment was carried out and the Winter-Spring crop 2018-19, Summer-Autumn 2019 and Fall-Winter 2019 on Hapli-Eutric-Gleysols soil in Tan Hoa commune, Chau Thanh A district, Hau Giang province (9°8967341'N, 105° 6174500'E) with physico - chemical properties such as: soil pH value was 5.50; electrical conductivity (EC) value was 0.9 mS/cm; available nitrogen (31.2 mgN/kg); available phosphorus (14.2 mg P_2O_5/kg); Al^{3+} exchange (2.17 meq/100 g); total acid (1.83 meqH^+/100 g); Organic matter (5.05% C); 47.0 % Clay; 50.4 % Silt; 2.60 % Sand, bulk density (1.05 g/cm^3).

Rice variety: IR50404 is commonly cultivated locally, suitable for 3 crops/year and yields 6-8 tons/ha.

Fertilizers: The experiment used 2 types of fertilizers: (1) Traditional fertilizers (common fertilizers) such as NPK (20-20-15), DAP (18-46-0), Urea (46% N) and KCl (60% K_2O) are fertilizers commonly used by farmers (2) and fertilizers produced by new technology such as controlled-release slow -release compound NPK 18-14-18 (NPK-CRF), Urea-humate (containing 46%N, 200 ppm MgO, 250 ppm CaO, 3,000 ppm SiO_2 and 1.2% humic acid, pH 7-9), K - humate (81% humic + fulvic, 19% K_2O; 1.4% Ca^{2+}, 100 ppm B, pH = 9 -10, moisture 12%).

Experimental designed:

The On-Farm Trials experiment was carried out on the fields of three adjacent farmers (to minimize variations in soil properties, access to water, variety, seeding density, fertilizer quantity and cropping schedule), corresponding to three replicates. The area for each rice-growing household is 1000m^2, cultivated and fertilized in two ways: (i) Control field (farmer's field): Traditional farming, sowing density 150kg/ha, urea, DAP, and common KCl, formula 92.2 N–82.8 P_2O_5–22.8 K_2O; (ii) Experimental field: Improved rice cultivation, sowing density of 130kg/ha, applying fertilizer with new technology (combination of NPK-CRF, K-humate, and urea-humate), formula 50.13 N– 39, 86 P_2O_5 – 30.04 K_2O.

Treatments:

(i) Control field: Fertilizer applied 4 times: 1st time: 1/5 amount of urea at 7 days after sowing (DAS); 2nd time: 1/3 of urea + 1/3 of DAP on 18 DAS; 3rd time: 1/3 Urea + 1/3 DAP + 1/2 NPK to 35 DAS; 4th time: 1/3 Urea + 1/3 DAP +1/2 NPK + 100% KCl in 45 DAS.

(ii) Experimental field: Fertilizer was applied 3 times at fully fertilized with NPK-CRF slow-release fertilizer before final tillage and plowed and buried in the soil; 1st application: 1/2 urea-humate + 1/2 DAP + 2/3 KCl on 18 DAS; 2nd application: 1/2 urea humate + 1/2 DAP + 1/3 KCl on 45 DAS. Mainly, K-humate fertilizer was applied only 2 kg/ha in Summer-Autumn and Autumn-Winter crops 2 times: 18 DAS and 45 DAS with 1/2 amount of potassium in each batch.

Rice cultivation techniques were done the same in farmer's fields. The only difference between the experimental and farmer fields is the sowing density, dosage and type of fertilizer.

Sampling, monitoring and data analysis:

Soil samples: were collected at the following times: (i) Early crop season 2018-2019; (ii) the end of the 2018-2019 cropping season; (iii) at the end of the 2019 crop; and (iv) at the end of the 2019 crop. Soil samples were collected by hand drill, depth from 0-20 cm at 5 locations in each experimental field, dried, soil for analysis: density, density, soil porosity, pH, EC, organic matter, available N, available P, exchangeable Al^{3+}, total acid.

Yield and yield components of rice: Number of panicles/m^2, number of seeds/panicle, percentage of firm seeds, 1000 seeds weight.

Actual yield (ton/ha): Determined on an area of 5m^2 and converted to humidity 14% by a hygrometer.

Soil analysis:

Soil samples were analyzed according to standard procedures (9); (10): Soil pH and soil EC (mS/cm) were extracted with distilled water (1:2.5) and measured with pH and EC meter. Organic matter (%C) was determined by the Walkley Black method. Easily digestible phosphorus analyzed by Bray II method. Available nitrogen (NH_4^+, NO_3^-) was extracted with 1M KCl and colorimetrically measured. The soil density is determined with a ring tube. Exchanged Al^{3+} and total acid was extracted with 1M KCl and determined by direct titration.

Data processing:

Collected and analyzed data are processed and calculated by Microsoft Excel program; Minitab 16.0 was used to test the T-test and (pairwise comparison) to compare the

Table 1. Soil properties comparison of three rice crops

Crop	Soil properties	Experimental field		t-value
		Improvement [(a)]	Farmers	
WS 18-19	Density (g/cm^3)	1.09 ± 0.06	1.13 ± 0.02	-3.68 ns
	Porosity (%)	52.1 ± 1.71	51.7 ±1.97	0.48 ns
	pH_{H20} (1:2.5)	4.81 ± 0.13	4.75 ± 0.14	0.83 ns
	$EC_{1:2.5}$ (mS/cm)	0.75 ± 0.11	0.65 ± 0.16	1.79 ns
SA 2019	Density (g/cm^3)	1.05 ± 0.06	1.08 ± 0.04	-3.62 ns
	Porosity (%)	54.2 ± 1.64	53.7 ± 1.93	0.58 ns
	pH_{H20} (1:2.5)	5.55 ± 0.22	4.57 ± 0.17	8.24 *
	$EC_{1:2.5}$ (mS/cm)	0.82 ± 0.04	0.96 ± 0.03	-4.02 ns
AW 2019	Density (g/cm^3)	1.08 ± 0.09	1.05 ± 0.06	3.62 ns
	Porosity (%)	54.2 ± 1.64	53.7 ± 1.93	0.58 ns
	pH_{H20} (1:2.5)	5.47 ± 0.02	5.03 ± 0.19	6.24 *
	$EC_{1:2.5}$ (mS/cm)	0.44 ± 0.05	0.49 ± 0.05	-2.65 ns

Note : (ns) is not significantly different; a statistically significant difference at 1% (*); ± represents the variation from the mean. [(a)] Improved field: sparse sowing, combined fertilization of NPK-CRF, urea-humate, and K-humate

difference in some soil properties, grain yield, and economic efficiency between the 2 experimental fields.

The efficiency of NPK-CRF, Urea-humate and K-humate fertilization on rice-intensive soil fertility

The results in Table 1 show no statistical difference in density, porosity and EC values in both experimental fields across all three rice crops. However, there is a difference in soil pH value between the improved fertilized fields and farmers' fields in the SA 2019 and AW 2019 rice crops. The improved fields have a higher pH (pH_{H20}> 5.0), which is significantly different. compared with soil pH in farmers' fields (pH_{H20} < 5.0).

The t-test in Table 2 shows that: In the WS crop 18-19, there was no difference in the content of organic matter, total acid, and Al^{3+} exchanged in the soil of the improved rice field compared with farmer fields; However, the content of N and P available in the soil was significantly increased after cultivation. In contrast, in the Summer -

Table 2. **S**oil fertility properties comparison of three treatments of rice cultivation

Crop	Soil properties	Experimental field		t-value
		Improvement [(a)]	Farmers	
WS 18-19	H^+ (meq/100g)	2.08 ± 0.09	1.97 ± 1.87	3.33 ns
	Al^{3+} exchange (meq/100g)	0.89 ± 0.18	0.87 ± 0.14	2.90 ns
	Available N (mg/kg)	40.0 ± 0.22	36.9 ±0.32	8.24 *
	$P_{Bray 2}$ (mg P_2O_5/kg)	31.6 ± 0.92	22.0 ± 0.75	9.44 *
	Organic matter (%)	5.05 ± 0.26	4.93 ± 0.14	4.85 ns
SA 2019	H^+ (meq/100g)	2.60 ± 0.09	3.37 ± 0.17	-6.36 *
	Al^{3+} exchange (meq/100g)	1.31 ± 0.18	2.75 ± 0.30	-7.54 *
	Available N (mg/kg)	77.9 ± 1.04	47.8 ± 1.69	13.2 *
	$P_{Bray 2}$ (mg P_2O_5/kg)	39.9 ± 0.74	33.8 ± 0.70	6.17 *
	Organic matter (%)	5.75 ± 0.12	4.94 ± 0.37	5.90 *
AW 2019	H^+ (meq/100g)	1.92 ± 0.24	2.83 ± 0.14	-9.50 *
	Al^{3+} exchange (meq/100g)	0.97 ± 0.08	1.83 ± 0.08	-6.66 *
	Available N (mg/kg)	50.1 ± 1.73	38.2 ± 1.90	6.35 *
	$P_{Bray 2}$ (mg P_2O_5/kg)	45.8 ± 0.70	34.2 ± 0.48	7.78 *
	Organic matter (%)	5.82 ± 0.22	4.98 ± 0.37	7.50 *

Note : (ns) is not significantly different; a statistically significant difference at 1% (*); ± represents the variation from the mean. [(a)] Improved field: sparse sowing, combined fertilization of NPK-CRF, urea-humate, and K-humate

Table 3. Rice yield and yield components comparation

Crop	Yield and yield components	Experimental field		t-value
		Improvement [(a)]	Farmers	
WS18-19	Number of panicle/m^2	582 ± 35.2	535 ± 18.8	3.97 *
	Filled seeds (%)	87.9 ± 0.22	87.1 ± 0.17	3.54 ns
	Ma Weight ss of 1000 seeds (g)	26.6 ± 1.17	26.1 ± 1.04	0.68 ns
	Yield (ton/ha)	6.92 ± 0.07	6.72 ± 0.09	5.22 *
SA 2019	Number of panicle/m^2	518 ± 43.6	483 ± 24.2	6.30 *
	Filled seeds (%)	81.6 ± 0.30	80.0 ± 0.24	4.52 ns
	Weight of 1000 seeds (g)	26.6 ± 1.19	26.8 ± 0.88	0.68 ns
	Yield (ton/ha)	5.94 ± 0.04	5.21 ± 0.03	6.99 *
AW 2019	Number of panicle/m^2	557 ± 18.6	497 ± 17.0	5.96 *
	Filled seeds (%)	80.7 ± 0.77	78.3 ± 0.58	1.12 ns
	Weight of 1000 seeds (g)	26.5 ± 0.67	26.7 ± 0.39	-0.98 ns
	Yield (ton/ha)	6.15 ± 0.18	5.63 ± 0.33	5.25 *

Note : (ns) is not significantly different; a statistically significant difference at 1% (*); ± represents the variation from the mean. [(a)] Improved field: sparse sowing, combined fertilization of NPK-CRF, urea-humate, and K-humate

Autumn and Autumn - Winter crops, K-humate supplementation significantly improved most soil fertility characteristics, such as increasing pH value, organic matter, organic N and P. It decreased total acid Al^{3+} exchangeable (Tables 1 and 2). This result shows that fields cultivated by improved methods when applying new generation fertilizers help improve soil chemical properties. The humate content in fertilizers over 2 seasons of application helps increase organic matter in the soil. The improved soil is significantly different from the farmers' conventional fertilizer fields. It was recorded that the effect of K-humate on the increase of helpful nutrient content in the soil (N, P, K) (11).

Effect of NPK-CRF, urea-humate and K-humate fertilization on rice yield and components

The results in Table 3 and Fig. 4 show that the yield of improvement treatment is always higher than the control field from all cropping seasons. It was mainly due to the increase of panicle number/m^2 (Fig. 1), while other yield components were not significantly different (Fig. 2, 3). These can be explained that the panicle shading area and canopy enclosure result in reduced light transmittance that leads to low light energy utilization efficiency, which is not favorable for the heading and mature stage of rice (12).

In general, the balanced NPK fertilization and new generation fertilizers help maintain and increase the number of panicles/m^2 and then increase rice yield and the biomass of straw. Adding K - humate in the Summer - Autumn and Autumn -Winter crops helps make the number of panicles/m^2 in the improved field different from that of the farmer's field. In addition, K - humate and urea humate may improve soil pH, N and P availability; increase the number of practical shoots; straw biomass and rice yield were both high and different from farmers' fields. It was also concluded that humic helps stimulate root growth through root morphology changes, regulates nutrient absorption activities, helps balance oxygen and hormones and increases crop yield (13).

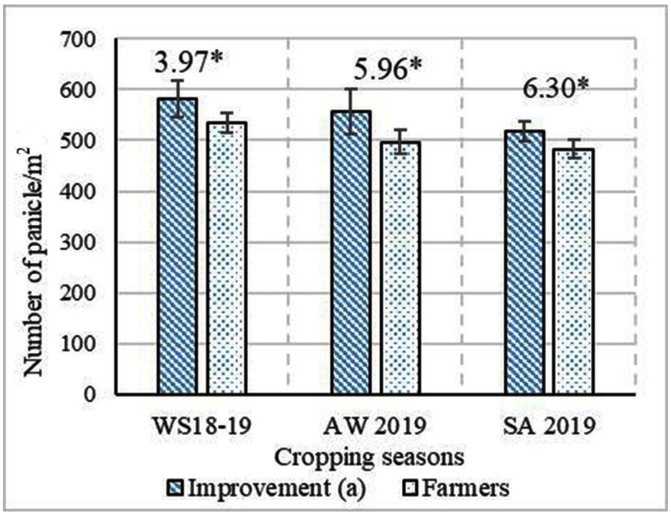

Fig. 1. Panicle Number/m^2 of treatments at different cropping seasons

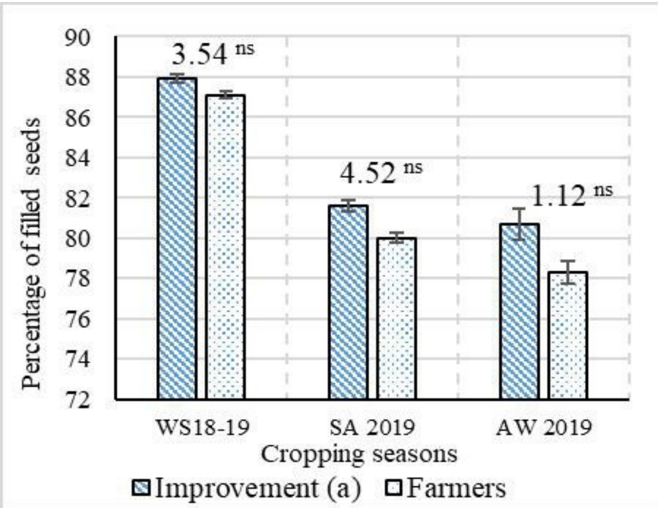

Fig. 2. Filled seeds (%) of treatments at different cropping seasons

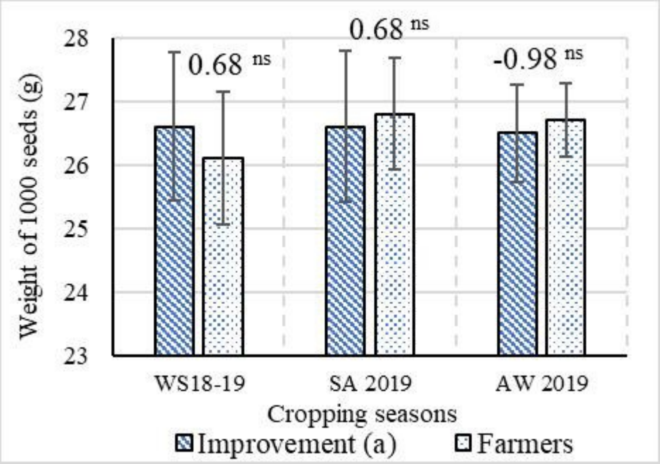

Fig. 3. Weight of 1,000 seeds (g) of treatments at different cropping seasons

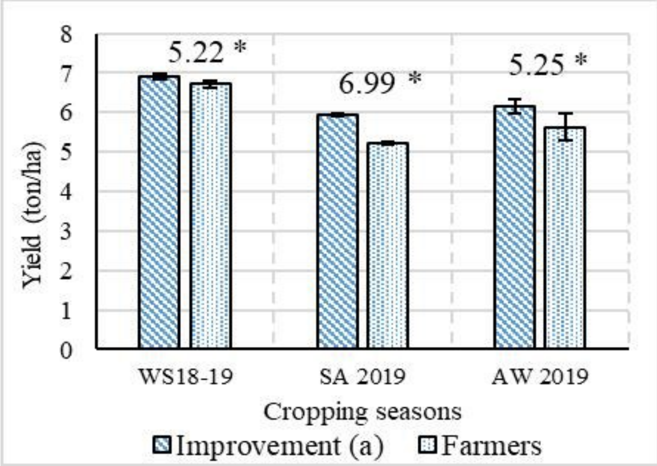

Fig. 4. Rice yield (ton/ha) of treatments at different cropping seasons

Note: (ns) is not significantly different; (*) a statistically significant difference at 1% from t test; ± the variation from the mean. [(a)] Improved field: sparse sowing, combined fertilization of NPK-CRF, urea-humate and K-humate.

Many studies have shown that application controlled-release N fertilizers (CRF), urea (polymer-coated and sulfur-coated) helped reduce the number of N fertilizer, increased rice yield by 5–6% on average (14-16). Crop productivity can be improved by nitrogen application, but the N losses and environmental pollution risk will increase as the accumulated mineral N exceeds crops demand (17). Improving the absorption and utilization rate of urea nitrogen in fertilizer plays a very important role in agricultural production and environmental protection (18). Controlled-release fertilizer can regulate nutrient release synchronously with crop nutrient absorption, which can significantly improve the nitrogen absorption of maize compared with common urea.

Conclusion

The experiment was repeated in 3 different seasons (spring, autumn and summer-autumn). This study confirmed new generation fertilizer application (NPK-CRF, urea-humate and K-humate) improved yield and yield component of the Winter-Spring rice cropping season (6.92 tons/ha), Summer-Autumn (5.94 tons/ha) and Autumn-Winter (6.15 tons/ha), which are different from farmers' fields. The combined application of NPK-CRF, urea-humate and K-humate fertilizers for rice in SA and AW crops significantly reduced the total acid content, Al^{3+} exchange in the soil and improved soil fertility pH and N nutrients. Available P, organic matter (%C). There is no difference in soil physical characteristics over the 3 rice crops. Finally, controlled-release fertilizer can improve soil fertility while increasing yield and yield components, nitrogen uptake and nitrogen utilization efficiency, all of which have a favorable yield and soil impact.

Authors contributions

TAT and BTT carried out the experiments. TAT and VQM conceived of the study and participated in its design and coordination. TAT performed the statistical analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare

Ethical issues: None.

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